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Review Article

Prioritizing biodegradable food packaging quality criteria: An importance-performance analysis

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Abstract

This study aimed to identify biodegradable packaging quality criteria in the food industry and evaluate their performance. The large volume of plastic waste results from poor food packaging management at the end of a package's life. Food manufacturing companies are seeking criteria to evaluate and improve the quality of biodegradable packaging. In this regard, criteria were identified through a systematic literature review of scientific databases. The weights of the criteria were calculated using the "Best-Worst Method". Finally, the "Importance-Performance Analysis" method was used to evaluate and prioritize the criteria. Some criteria had the highest importance, but their performance was low, which indicates the most significant weakness of the packaging system. In contrast, some criteria had the highest level of importance and performance, which indicates an effective response to market needs and quality requirements. Sensitivity analysis showed that although criterion rankings change across different weighting scenarios, the magnitude of these changes varies by criterion. Using a mixed-methods approach and presenting a classification of the dimensions of quality for biodegradable packaging, this study serves as a valuable resource for food manufacturers in formulating strategies to enhance sustainable packaging.

Keywords: Best-Worst Method, Biodegradable packaging, Food industry, Packaging quality, Systematic literature review.

Introduction

The increasing use of packaging has become a strategic sustainability concern for managers in the food industry, as the growing reliance on packaged foods is accompanied by mounting environmental and resource-related challenges. Recent evidence highlights the enduring importance of packaging materials in the food sector and the escalating challenges associated with the use of materials with limited biodegradability, particularly plastics (Joint Research Centre, 2026). At the same time, recent research emphasizes that sustainable food packaging must be evaluated based on criteria such as food preservation, consumer needs, and end-of-life impacts, in addition to environmental performance (Zhang, 2026). Furthermore, packaging is increasingly recognized as a strategic component of the food supply chain, with its design and

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functionality influencing food loss and waste, as well as broader sustainability implications (Qazanfarzadeh et al., 2026). With the growth of the food industry, the demand for high-quality food is increasing, intensifying competition in the sector, and encouraging companies to adapt to consumers' demands for healthy and high-quality food (Kumari et al., 2024). Additionally, companies aim to achieve sustainable development goals while reducing production and delivery costs, gaining consumer satisfaction and trust, and gaining a competitive advantage and profit (Awlqadr et al., 2025). Meanwhile, packaging plays an important role in creating positive feelings, facilitating customers' decision-making, maintaining product quality, and extending shelf life (Ingrassia et al., 2026; Pålsson & Sandberg, 2022). The concept of sustainability emphasizes meeting present needs without compromising the ability of future generations to meet their own needs, and in 2015, the United Nations General Assembly adopted goals such as ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture (Vaikma et al., 2025). This concept encompasses various economic, social, and environmental dimensions. In recent years, as human lifestyles have changed in different societies, the demand pattern for food has also changed, and consumers' tendency to use packaged foods has increased. Despite the numerous benefits of these products, the increase in the consumption of packaged foods has led to an increase in the volume of waste produced worldwide (Chakori et al., 2026).

Waste, especially food waste and packaging, is considered a major issue in the food industry, with more than two-thirds of the packaging produced globally being used in the food industry, which has created problems with recycling and food safety. In addition, global statistics show that plastics account for 42.2% of the global packaging materials market (Vaikma et al., 2025). The growing volume of non-recyclable, non-degradable plastic waste and its negative environmental effects have led industries to produce biodegradable packaging to reduce waste and harmful environmental impact. Packaging helps preserve food, provide information, and facilitate transportation, and as a barrier against external contaminants such as microorganisms, dust, gases, and light, it plays an important role in maintaining food quality and safety (Cheng et al., 2024a). Biodegradable packaging has been developed to replace conventional plastics in various types of packaged foods and can improve packaging properties, such as thermal stability, barrier properties, and mechanical strength. The use of plants and biodegradable materials in sustainable food packaging is an important step in reducing negative environmental effects (Kumari et al., 2024). Owing to population growth and increasing demand for food, the food system is recognized as a major driver of global environmental degradation; according to studies, approximately 70% of global freshwater consumption, 38% of the world's land use, and one-third of global greenhouse gas (GHG) emissions are affected by this system. Also, it is predicted that if the current production and consumption continue, the environmental impact can increase by 90% by 2050 (Shah et al., 2024).

Therefore, addressing the environmental challenges associated with packaging requires a fundamental shift toward more sustainable packaging systems. A recent study covering 19 EU member states indicates that in 2024, the per capita volume of packaging materials placed on the market was approximately 98 kilograms, with food and beverages accounting for the largest share. Furthermore, plastic was the only packaging category to show an upward trend between 2011 and 2025, registering an 11% increase in absolute terms. These findings underscore the significant and growing role of packaging materials in the food sector and reinforce the need to develop more sustainable packaging solutions capable of addressing environmental concerns while maintaining the functional requirements of food products. The trend regarding the placement of plastic packaging on the market in the studied EU member states is illustrated in **Figure 1** (Joint Research Centre, 2026).

With the advancement of technology and the increasing attention of consumers and industries to environmental issues, traditional packaging methods are no longer able to fully meet emerging needs, including extended shelf life, improved safety and product quality, ease of use, environmental friendliness, and reduced food waste. In response to these challenges, a new generation of packaging has

been introduced, called “biodegradable packaging” (Khodaei et al., 2023).

This type of packaging can play a key role in reducing food waste and improving resource efficiency throughout the supply chain (Pålsson & Sandberg, 2022). However, plastic waste has become a growing concern worldwide owing to its non-degradability, harmful environmental effects, and contribution to global warming. This global issue has increased the demand for biodegradable packaging and has led companies to produce this type of packaging for food products (Koirala et al., 2025).

Due to the emergence of the concept of biodegradability in line with the goals of sustainable development and reducing the harmful effects on the environment, numerous studies have been conducted in the field of biodegradable packaging (Soundara Rajan & Wani, 2025). Previous studies have focused on the investigation of biodegradable raw materials, production technologies, mechanical properties, development barriers, and environmental effects of these types of packaging. Some studies have examined consumer and market acceptance.

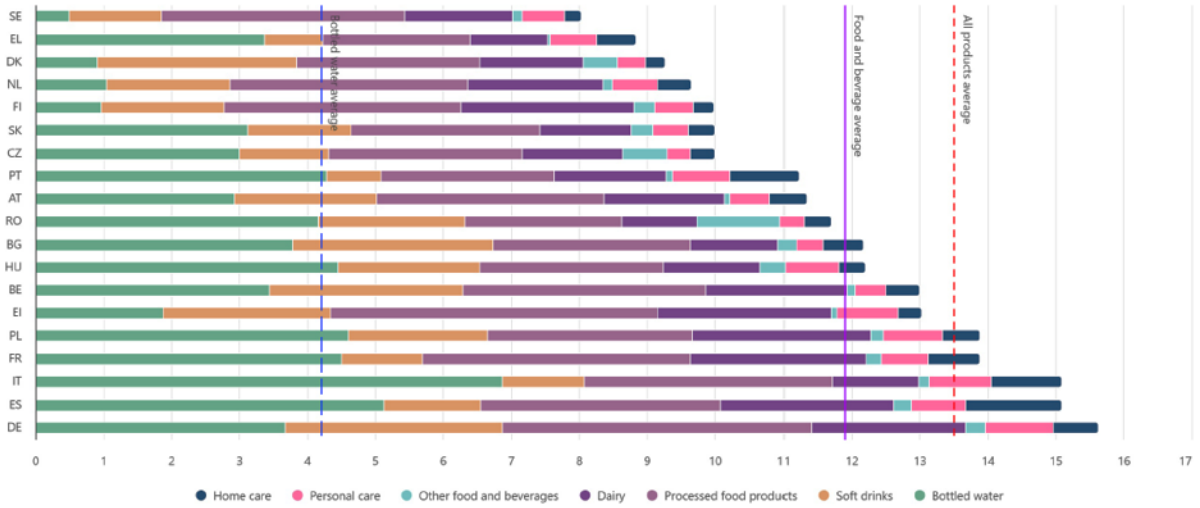

Figure 1. Plastic packaging placed on the market (kg per capita), 2011–2025 (Joint Research Centre, 2026).

Despite the growing body of research on the environmental effects of food systems and biodegradable packaging, a comprehensive framework for identifying the quality dimensions of this type of packaging in the food industry has not yet been presented. Previous studies have focused on environmental and technical aspects, with less attention paid to other critical economic, logistical, functional, market, and customer dimensions of sustainability. This dispersion in criteria and the lack of a unified perspective may hinder the systematic assessment and improvement of biodegradable packaging. This study aims to fill this research gap by identifying a comprehensive set of criteria affecting the quality of biodegradable packaging and achieving an appropriate classification of these criteria for the food industry. Ultimately, the identified criteria can provide a basis for developing a comprehensive framework for assessing the quality of biodegradable packaging and guiding decision-makers and food industry manufacturers in developing and adopting more environmentally friendly packaging solutions, increasing competitive advantage, and adhering to social responsibility.

Accordingly, this study addresses the following research questions:

RQ1. What are the key quality criteria and dimensions of biodegradable packaging in the food industry?

RQ2. How do the identified criteria perform in terms of importance and performance in the food industry?

From conventional to biodegradable food packaging

Packaging is one of humanity's most significant achievements, playing a fundamental role in various aspects of our lives. The evolution of packaging systems over time has been driven by numerous factors, including regulatory and policy changes, technological advancements, rising global demand for food and energy, and environmental concerns (Shaikh et al., 2021). Food packaging encompasses a set of techniques and methods used to prevent spoilage, extend shelf life, and improve food transportation and storage conditions (Tukenmez Emre et al., 2025). While traditional packaging fulfilled its primary functions in past decades, it posed challenges in waste management and faced limitations in addressing the evolving needs of consumers, businesses, and supply chains, particularly because of its reliance on fossil-based resources (Soundara Rajan & Wani, 2025). In recent years, concerns regarding sustainability and the mitigation of adverse environmental impacts have played a vital role in driving packaging innovation. Furthermore, consumer choices and preferences for eco-friendly products influence the success and adoption of sustainable food packaging. Consequently, research and industrial practices have gradually shifted from conventional packaging to more sustainable solutions. Sustainable food packaging has emerged as a way to meet essential functional requirements while reducing environmental impact. Consequently, recent studies have increasingly focused on packaging systems in terms of material efficiency, waste reduction, recyclability, and life-cycle impacts (Daramola et al., 2025; Espinoza-Orias & Lundquist, 2025). Similar research has addressed the impact of sustainable packaging on enhancing efficiency throughout the food supply chain (Cozzolino & De Giovanni, 2023; Versino et al., 2023). In this context, biodegradable materials are gaining attention as alternatives to conventional petroleum-based plastics. Previous studies have reported the use of bio-based and biodegradable materials for food packaging to reduce plastic dependence while meeting necessary packaging performance requirements (González-López et al., 2023; Shaikh et al., 2021). Consumer-related factors also influence the acceptance of sustainable and biodegradable packaging; while consumers generally hold positive attitudes toward eco-friendly packaging, difficulties in identifying and properly disposing of fully biodegradable packaging affect market acceptance (Bojanowska & Sulimierska, 2023; Lin et al., 2025). Ultimately, the shift toward biodegradable packaging reflects a move from a narrow focus on materials, protection, and functionality to a broader understanding of packaging sustainability. Based on the reviewed literature, biodegradable packaging must simultaneously address functional, environmental, economic, logistical, and market-related requirements. This multidimensional nature of packaging performance provides a basis for evaluating the quality of biodegradable packaging, going beyond the mere biodegradability of the materials, which will be examined in the next section.

Quality dimensions of biodegradable food packaging

The quality of biodegradable packaging in the food industry is a multidimensional concept that simultaneously meets the functional requirements of traditional packaging and environmental sustainability standards, encompassing functional, technical, economic, logistical, customer-oriented and market dimensions. Food packaging serves as a strategic tool for ensuring the quality, safety, and shelf life of food products, acting as an effective barrier against biological, chemical, and physical spoilage agents (Dirpan et al., 2023). Sustainable food packaging methods offer innovative solutions for enhancing food quality and safety, extending shelf life, and mitigating environmental impact (Tukenmez Emre et al., 2025). However, evaluating the quality of biodegradable packaging requires consideration of its environmental impact throughout the product's entire life cycle. In this context, “Life Cycle Assessment” (LCA) is employed as a key analytical tool to examine the environmental effects of packaging. This assessment considers criteria such as raw material consumption, packaging weight, transportation, energy usage, and recyclability or biodegradability (Yilmaz et al., 2024).

From a functional perspective, these packaging materials must act as barriers against the permeation of gases, moisture, and light. From a technical standpoint, attributes such as mechanical

strength, thermal stability, processability, and compatibility with manufacturing technologies are of great importance. Biodegradable materials used in the packaging industry include proteins, polysaccharides, lipids, and biopolymers; these materials have attracted attention as potential alternatives to conventional packaging, although their environmental performance and biodegradability depend on material composition and disposal conditions (Soundara Rajan & Wani, 2025). Furthermore, the incorporation of nanocomposites into the production of such packaging has enhanced technical and functional properties, including optical characteristics and mechanical strength. Some of these materials possess novel functional properties, such as antioxidant and antibacterial activity, which can play a significant role in extending shelf life and preserving food quality (Soundara Rajan & Wani, 2025). It should also be noted that not all bioplastics are biodegradable, and the biodegradability of a material does not necessarily imply its complete decomposition in the environment (Dörnyei et al., 2023). Nevertheless, packaging plays a crucial role in the food industry by preventing spoilage, maintaining quality, and reducing food waste, and it is recognized within the supply chain as a "silent seller" (Yilmaz et al., 2024). Biodegradable packaging has garnered significant attention as an alternative to petroleum-based plastics. Such packaging can decompose under composting conditions and offers benefits such as reduced plastic waste accumulation, lower carbon emissions, and decreased reliance on fossil fuels (Cheng et al., 2024b). Despite these advantages, biodegradable packaging faces limitations compared to conventional plastics, including inferior barrier properties, lower thermal resistance, reduced mechanical strength, and higher production costs (Cheng et al., 2024b). When producing high-quality biodegradable packaging, factors such as raw material availability, manufacturing process requirements, economic feasibility, and the cost-effectiveness of raw materials relative to conventional packaging are critical considerations. Consequently, production strategies must strike a balance between cost, performance, and environmental considerations (Daramola et al., 2025). Furthermore, the raw materials used must be compatible with the requirements for the storage, handling, transport, and distribution of food products. Research into sustainable packaging and the circular economy identifies packaging weight and raw material consumption as key factors influencing system efficiency and the optimization of logistics operations throughout the product lifecycle (Cozzolino & De Giovanni, 2023; Espinoza-Orias & Lundquist, 2025). Therefore, evaluating the quality of biodegradable packaging requires attention to economic and logistical aspects alongside technical considerations.

Furthermore, the quality of biodegradable packaging is defined not only by its physical and environmental attributes but also by consumer perception, visual appeal, and ease of use of the product. Even when consumers have a positive attitude toward eco-friendly packaging, a lack of information regarding its identification and proper disposal can influence market acceptance (Bojanowska & Sulimierska, 2023; Lin et al., 2025). Additionally, consumer perceptions of food product sustainability are shaped by factors such as packaging and label information. Therefore, evaluating packaging quality requires the simultaneous consideration of consumer requirements and market acceptance criteria (Vaikma et al., 2025).

A review of prior studies reveals that research on biodegradable and sustainable food packaging has addressed various aspects of packaging quality. Some studies have focused on enhancing technical and functional characteristics ,such as mechanical properties, barrier performance, and extension of food shelf life (Cheng et al., 2024b; Singh et al., 2025). Others have emphasized balancing cost, performance, and environmental considerations, alongside life-cycle assessments of packaging impacts (Daramola et al., 2025; Espinoza-Orias & Lundquist, 2025). Additionally, other research has examined consumer attitudes, the role of on-package information and labeling, and the influence of consumer awareness on the market acceptance of biodegradable packaging (Bojanowska & Sulimierska, 2023; Lin et al., 2025; Vaikma et al., 2025). Overall, the evaluation of sustainable packaging highlights functional and technical, economic and logistical, environmental, and customer-oriented and market dimensions.

Accordingly, this study addresses the challenge of identifying and organizing quality criteria for biodegradable packaging into distinct dimensions, while simultaneously evaluating the importance and performance of these criteria within the food industry. Indeed, merely identifying the desirable characteristics of biodegradable packaging is insufficient; it is also essential to determine their relative importance and their relationship to performance. Accordingly, this study first identifies the criteria and dimensions of biodegradable packaging quality in the food industry through a systematic literature review (SLR); it then determines the criteria weights using the best-worst method (BWM). Subsequently, the BWM-derived weights are used to represent criterion importance, while performance data collected through a second questionnaire are used to construct the importance-performance analysis (IPA) matrix. In doing so, the study aims to provide a structured framework for assessing the quality of this type of packaging, thereby laying the groundwork for identifying criteria that require improvement and prioritizing actions to enhance quality within the food industry.

Materials and Methods

In this study, the criteria affecting the quality of biodegradable packaging were evaluated. Because this type of packaging is multifaceted, several factors affect its quality. Identifying and prioritizing these factors can support decision-making, strategy development, and packaging quality improvement in the food industry.

To identify effective criteria and reduce researcher bias, we conducted a SLR to extract an initial set of criteria based on theory and prior studies (**Fig. 2**). However, the extracted criteria do not have the same importance, and some dimensions play a more decisive role in assessing the quality of biodegradable packaging. Accordingly, identifying these criteria alone is insufficient for decision-making, and determining their relative importance is necessary for decision-making. In this regard, "Best-Worst" multi-criteria decision-making methods were used to determine the weights and prioritize the criteria. This method was selected because it requires fewer pairwise comparisons than traditional methods, which reduces the inconsistency in judgment and improves the accuracy of weight estimation. Despite the ability of the BWM to determine the relative importance of criteria, this method alone cannot assess the performance status of the criteria in the industry. Therefore, in the next stage, IPA was used to simultaneously examine the two dimensions of "importance" and "performance." In addition to identifying strengths and weaknesses, this analysis enables the prioritization of improving biodegradable packaging quality (**Fig. 2**).

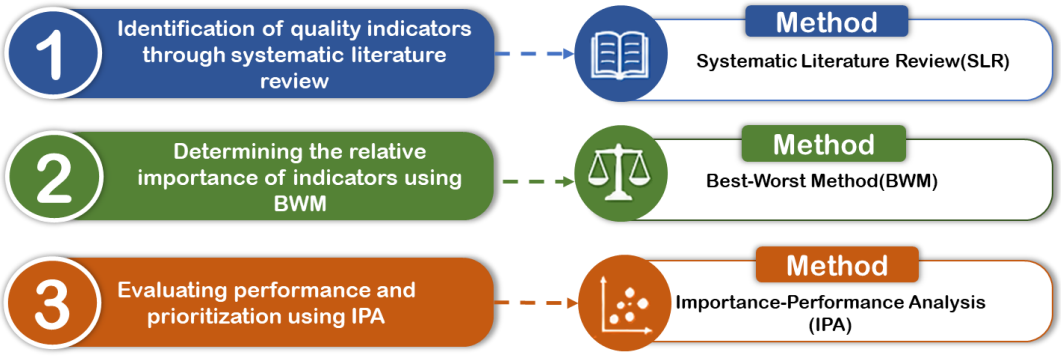

Figure 2. Methodology process.

In this study, a combined exploratory-analytical approach was used to identify, weigh, and analyze the IPA of the biodegradable packaging quality criteria in the food industry. This study was designed in three phases. In the first phase, biodegradable packaging quality criteria were extracted through a SLR. In the second phase, the relative importance of each criterion was determined using the "Best-

Worst" multi-criteria decision-making method. In the third phase, the performance of the criteria was evaluated through a survey of experts, and finally, the status of each criterion was determined using IPA for the analysis and prioritization of improvements.

Systematic literature review

A SLR methodology was employed to extract quality criteria for biodegradable packaging within the food industry. This approach facilitates a structured search process, which helps minimize researcher bias while enhancing the transparency of the analysis and synthesis of existing studies (Amoozad Mahdiraji et al., 2024; Amoozad Mahdiraji et al., 2026). Furthermore, the SLR method ensures coherence throughout the entire research process (Razavi Hajiagha et al., 2026).

In the SLR method, the use of a protocol is essential to establish order and guarantee transparency across the research (Razavi Hajiagha et al., 2026). The systematic review process was designed and executed based on the PRISMA framework to precisely extract the quality criteria for packaging. In contrast, other frameworks, such as the TCCM, focus on classifying literature based on theory, while the SPAR-4 framework centers on standardizing reporting procedures and providing an overarching structure (Razavi Hajiagha et al., 2026). Among these three frameworks, PRISMA was selected. The SLR process in this study was conducted in five stages.

Step 1: Determining research questions. The research objectives were formulated through an iterative refinement and scoping process designed to ensure both theoretical contribution and methodological rigor in the SLR. In this step, an initial search was conducted across reputable databases using preliminary keywords. This process yielded three outcomes: first, the scope of the research was defined. Second, key terms were identified for the final search. Finally, the definitive research objectives were established. This step took about two weeks. Research questions were designed to control the search process and extract relevant studies. These questions are:

1. "What are the main dimensions of biodegradable packaging quality in the food industry?"

2. "What criteria play a role in assessing the quality of biodegradable packaging?"

Step 2: Determining the inclusion and exclusion criteria of studies. Defining the research objectives provided a framework for establishing inclusion and exclusion criteria for existing studies. These criteria were set to enhance the precision and focus of the search process. Consequently, five filters were selected: publication year, language, review type, source type, and paper type. Specifically, the inclusion criteria consisted of a publication period from 2020 to 2026, the English language, journal articles, research and review articles, and studies related to biodegradable packaging quality in the food industry.

Step 3: Search for studies and database selection. In this step, with the help of the protocol prepared in step (2), the search process in the databases was carried out. Four databases were selected. Four databases were selected: Scopus, Web of Science, Google Scholar, and ProQuest databases were selected due to their extensive coverage and high scientific credibility in academic studies (Amoozad Mahdiraji et al., 2024; Razavi Hajiagha et al., 2026). Initial keywords were selected based on preliminary searches and subsequently refined through further reviews. This process facilitated the consolidation of existing keywords and the identification of emerging ones. Consequently, all keywords relevant and aligned with the research objectives were gathered. In this vein, the keywords were employed to conduct searches within the databases as follows: ("Biodegradable packaging" OR "Sustainable food packaging" OR "Food packaging quality" OR "Eco-friendly packaging") OR ("Biodegradable packaging" AND "Sustainable food packaging" AND "Food packaging quality" AND "Eco-friendly packaging"), and ("Biodegradable packaging" AND "Sustainable food packaging" AND "Food packaging quality" AND "Eco-friendly packaging"), and ("Biodegradable packaging" OR "Sustainable food packaging" OR "Food packaging quality" OR "Eco-friendly packaging"). The search process took approximately two months, and all researchers were involved in this step.

Step 4: Article screening. In this step, the articles obtained from the previous steps were collected, and

the first duplicate articles were removed. The titles, abstracts, and full texts of the remaining articles were screened for eligibility. A total of 198 articles were selected; 24 were removed because of duplication, 48 were removed after reviewing the title, 61 were removed after reviewing the abstract, and 35 were removed after evaluating the full texts. Finally, 30 articles matched the research topic and were included in the final stage of the analysis (**Fig. 3**).

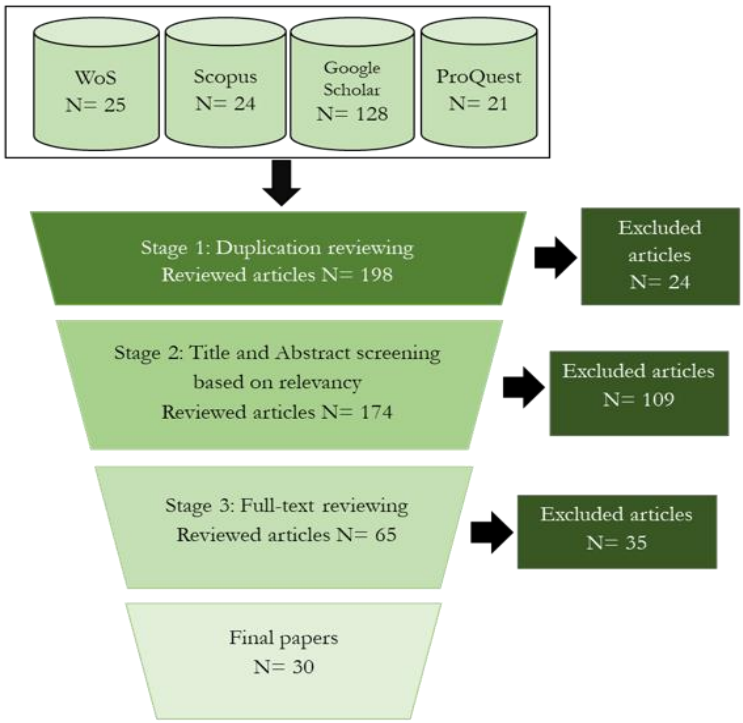

Figure 3. Screening of articles.

Step 5: Data Extraction and Analysis. Data relevant to the research topic were extracted from 30 articles that were included after screening in the previous four steps. Using qualitative content analysis, we identified and categorized criteria related to the quality of biodegradable packaging. Two researchers carried out the extraction process, which took approximately two months. The output of this stage was the extraction of 19 quality criteria in four main dimensions: functional and technical, environmental, economic and logistical, and market and customer-oriented.

Best-worst method

Following the identification of biodegradable packaging quality criteria through the SLR, the second phase focused on determining the relative importance and prioritization of the identified criteria using the BWM. Among the existing methods in multi-criteria decision-making, the BWM was used because the criteria do not have the same importance, and some of them play a more decisive role in assessing the quality of biodegradable packaging.

The BWM method, introduced by Rezaei (2015), is one of the new weighting approaches in multi-criteria decision-making that has attracted attention because of the need for fewer pairwise comparisons and high performance in quadrants such as consistency and reliability (Rezaei, 2016).

This method involves selecting the best and worst criteria from the set of selected criteria and making pairwise comparisons between them and other criteria. Finally, the optimal weight of the criteria is calculated by solving a mathematical optimization

model. In addition, in this method, a formula is used to calculate the inconsistency rate to examine the consistency of the experts' judgments.

The steps for implementing the best-worst method are as follows:

Step (1): Determine the criteria. In this step, 19 criteria were considered decision-making criteria.

Step (2): Determine the best and worst criteria. The experts determined the most and least important criteria among the existing ones.

Step (3): Comparing the best criterion with other criteria. In this step, the degree of preference of the best criterion over others was determined using a scale of 1–9.

Step (4): Comparing other criteria with the worst criterion. In this step, the degree of preference of each criterion over the worst one was determined.

Step (5): Calculate the optimal weights of the criteria. After forming the comparison vectors, the final weights of the criteria were calculated by solving the BWM optimization model. The BWM model is defined as follows (**Eq. 1**) (Rezaei, 2016):

$$\begin{gathered} Min\xi \\ s.t. \\ ,for\ all \left|\frac{w_B}{w_j} - C_{Bj}\right| \le \xi \\ ,for\ all \left|\frac{w_j}{w_w} - C_{jw}\right| \le \xi \\ \sum_{j=1}^{n} w_j = 1 \\ w_j \ge O, for\ all \end{gathered} \qquad (1)$$

Where w^* is $(w_1, w_2, \dots, w_n)$ denotes the optimal weight vector of the decision criterion, w_B is the weight of the best criterion, w_W is the weight of the worst criterion, w_j is the weight of the criterion j, where $j = 1,2, \dots, n$, C_{Bj} is the preference of the best criterion over the criterion j, obtained from experts using the 1–9 comparison scale, C_{jW} is the preference of the criterion j over the worst criterion, obtained from experts, ξ is the maximum absolute deviation to be minimized in the optimization model, n is the total number of evaluation criteria. The normalization constraint ensures that the sum of all criteria weights is equal to 1, $w_j \ge 0$ is the non-negativity constraint, which indicates that all criterion weights are non-negative.

The above model was solved for all dimensions separately, and the weights were obtained. In addition, the consistency ratio was calculated for each dimension (**Eq. 2**). The lower the value of this indicator, the higher the consistency of the judgment.

$$CR^{(s)} = \frac{\xi^{(s)}}{CI^*} \qquad s = 1,2,\dots,S \qquad (2)$$

CI^* is the incompatibility reference value based on the number of criteria from the standard table (**Table 1**) (Rezaei, 2016), $\xi^{(s)}$ is the optimal value of the model in scenario (s).

To aggregate the experts' judgments, the BWM model was solved independently for each expert, resulting in individual weight vectors. Subsequently, the final weight of each criterion was calculated by taking the arithmetic mean of the corresponding weights across all experts. This procedure represents the aggregation of individual priorities rather than the aggregation of individual judgments before optimization. The aggregated weight of criterion (j) was calculated as follows (**Eq. 3**):

$$W_j^G = \frac{1}{n}\sum_{k=1}^{n} W_j^k \qquad (3)$$

W_j^G: Final aggregated weight of criterion j

W_j^k: Weight of criterion j obtained from the BWM model for expert k.

$k = 1,2, \dots, n$: Number of experts

Finally, the weights obtained from the BWM were used as a measure of the importance of the criteria in the next stage of the IPA.

Table 1. Incompatibility reference value for BWM.

CBW	1	2	3	4	5	6	7	8	9
CI*	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Table 2. Identified quality criteria and their dimensions.

Main dimensions	Criterion	Description	Reference
Functional and Technical	PT1- Packaging mechanical stability	Resilience and flexibility of packaging material against mechanical forces, deformation, or failure during production and transportation stages	(Shah et al., 2023)
	PT2- Product shelf-life preservation	Barrier properties of packaging against water vapor and moisture penetration, as well as antimicrobial and antioxidant activities	(Bhowmik et al., 2024)
	PT3- Resistance to environmental penetration	The ability of packaging material to prevent the ingress of gases, oxygen, and moisture, and to provide protection against external factors	(Shi et al., 2024)
	PT4- Food Safety Assurance	Ensuring the safety of food-contact packaging against bacteria and food poisoning	(Ghasemlou et al., 2024)
Environmental	E1- Packaging biodegradability	The capability of the packaging material, depending on the type of polymer, to undergo biodegradation under suitable conditions, such as in soil or compost	(González-López et al., 2023)
	E2- Packaging material recyclability	The capability to recover and reprocess packaging materials for reuse in the production process	(Yadav et al., 2025)
	E3- Reduction of life -cycle environmental impacts	The use of raw materials, manufacturing processes, and end-of-life and waste management with a focus on environmental impacts as alternatives to plastics	(Ghasemlou et al., 2024)
	E4- Energy efficiency in packaging production	Manufacturing packaging with minimal energy consumption during the production process, without compromising the expected functional properties	(Yadav et al., 2025)
Economic and Logistics	EC1- Economic efficiency of packaging production	The ability to produce packaging that maintains functional properties while remaining cost-effective in terms of raw materials and large-scale production processes	(Karnwal et al., 2025)
	EC2- Packaging logistics efficiency	The degree to which packaging characteristics align with the requirements of the transportation process, while maintaining the packaging's functionality and preventing issues during operational processes	(Balaban & Puška, 2022)
	EC3- Minimization of raw material waste	Capabilities of the production system process in reducing raw material waste during manufacturing and packaging processing	(Balaban & Puška, 2022)
	EC4- Reusability of packaging materials	Packaging design aimed at preservation and durability for repeated reuse	(Espineda et al., 2025)
	EC5- Packaging space efficiency	Packaging design is aimed at preserving the product and its functionality while minimizing the space occupied during storage and transportation	(Rios et al., 2021)
Market and Customer-oriented	M1- Packaging visual quality	Packaging design based on visual criteria that influence consumer perception	(Bojanowska & Sulimierska, 2023)
	M2- Printability and brand identity capability	Printability and clarity of packaging graphics, while maintaining functional capabilities	(Żołek-Tryznowska & Holica, 2020)
	M3- Consumer acceptance and trust	Consumers' willingness to use packaging and their confidence in the safety and quality of the packaging in preserving the product	(Thota et al., 2020)
	M4- Customer environmental satisfaction	Consumers' satisfaction and perception regarding the extent of its environmental compatibility and the reduction of negative impacts	(Lin et al., 2025)
	M5- Packaging user-friendliness	The level of ease with which a consumer can use the packaging for activities such as opening, resealing, carrying, and storing the product	(Turan et al., 2024)
	M6- Product information transparency	The clarity and legibility of information provided on packaging, designed to facilitate the consumer decision-making process	(Żołek-Tryznowska & Holica, 2020)

Performance evaluation of criteria

After the relative importance of the criteria was determined using BWM, the performance status of the biodegradable packaging quality criteria in the food industry was determined. Because weighting criteria alone cannot determine the actual performance status of the criteria, IPA was used in this study.

This analysis method was first introduced by (Martilla & James, 1977) and is one of the methods for analyzing and prioritizing criteria based on the two dimensions of “importance” and “performance.” This method allows for the identification of strengths, weaknesses, and improvement priorities.

In this study, the weights obtained from the BWM were considered as importance values. After collecting the questionnaires, the average performance for each criterion was calculated. Subsequently, an IPA matrix was formed by combining the importance and performance values. The horizontal axis represents performance, and the vertical axis represents importance.

Based on the average values, the criteria were classified into four main quadrants.

Quadrant I: High importance-low performance: "The criteria in this quadrant are an urgent priority for improvement".

Quadrant II: High importance-high performance: "The criteria in this quadrant are the strengths of the system, and their current status should be maintained".

Quadrant III: Low importance-high performance: "The criteria in this quadrant represent areas where resources allocated exceed the criterion's importance; further resource allocation requires careful review".

Quadrant IV: Low importance-low performance: "Due to their lower importance compared to Quadrant 1, the criteria in this Quadrant are lower priorities for improvement".

In Importance–Performance Analysis (IPA), the intersecting lines separating the four quadrants are determined based on the overall mean scores of importance and performance. These means are calculated from the assessment results and serve as reference points for classifying the criteria into the four IPA quadrants.

Finally, IPA analysis allows for the identification of the gap between the importance and performance of biodegradable packaging quality criteria and forms the basis for providing executive and management priorities to improve packaging quality in the food industry.

Results and Discussion

To address the research questions regarding the identification and prioritization of quality criteria for biodegradable packaging in the food industry, this study followed a structured methodology. First, relevant criteria influencing the quality of biodegradable packaging were identified through a SRL. Next, the relative importance of these criteria was determined by industry experts using BWM. Subsequently, the experts completed a second questionnaire to assess the performance of these criteria. Finally, an IPA matrix was constructed by evaluating the importance and performance of the criteria in conjunction. The results of the study, presented in accordance with the methodological steps, are outlined below.

To address the first question, 19 criteria influencing the quality of biodegradable packaging were identified and classified into four main dimensions: functional and technical, environmental, economic and logistics, and market and customer-oriented. (**Table 2**)

To determine the importance weights of the identified quality criteria using the BWM method, a questionnaire based on the 19 identified criteria was designed and distributed among nine experts. The experts were divided into two groups: academic and industrial. **Table 3** presents the profiles of the experts. Initially, the questionnaire and a document summarizing the objectives and activities undertaken were sent to all experts via email. After one month, all completed questionnaires were collected. The performance of each criterion was measured using a 5-point Likert scale.

To address the second research question, the importance weights of the biodegradable packaging quality criteria were calculated using the BWM method based on the experts' judgments. The results are presented in **Table 4.**

To evaluate the performance of the identified biodegradable packaging quality criteria, nine academic and industrial experts completed a second questionnaire. The mean performance scores were calculated for each criterion and analyzed alongside the corresponding importance weights obtained through the BWM method. Based on these two dimensions, the criteria were classified into the quadrants of the IPA matrix. **Table 5** presents the

importance weights, mean performance scores, and resulting IPA quadrant classifications.

Table 3. Profiles of the experts.

Experts	Age	Type (A=Academia; I=Industrial)	Experience	Role
E1	42	A	9	PhD
E2	41	I	12	CEO manager
E3	40	A	10	PhD
E4	63	I	22	CEO manager
E5	49	A	18	PhD
E6	37	A	8	PhD
E7	44	I	15	CEO manager
E8	35	I	9	CEO manager
E9	51	A	10	PhD

Table 4. Relative importance weights of the quality criteria obtained using BWM.

Main dimensions	Dimensions weight	Criterions code	The weight of the criteria in each dimension	Final weight of the criterion
Functional and technical	0.214	PT1	0.152	0.0325
		PT2	0.238	0.0509
		PT3	0.205	0.0439
		PT4	0.405	0.0867
Environmental	0.389	E1	0.235	0.0914
		E2	0.264	0.1026
		E3	0.351	0.1365
		E4	0.150	0.0584
Economic and logistic	0.176	EC1	0.290	0.0510
		EC2	0.230	0.0405
		EC3	0.200	0.0352
		EC4	0.150	0.0264
		EC5	0.130	0.0229
Market and customer oriented	0.221	M1	0.165	0.0365
		M2	0.120	0.0265
		M3	0.295	0.0652
		M4	0.185	0.0409
		M5	0.139	0.0309
		M6	0.095	0.0210

Based on the importance weights obtained through the BWM method (**Table 4**) and the mean performance scores (**Table 5)**, an IPA matrix was constructed to simultaneously assess the relative importance and performance of the biodegradable packaging quality criteria. The matrix was divided into four quadrants using the mean performance and importance scores as reference points. The position of each criterion within the matrix indicates its relative importance and performance level, thereby providing a basis for identifying improvement priorities and allocating managerial attention to the criteria requiring greater improvement efforts. In the Importance–Performance Analysis (IPA), the intersection lines separating the four quadrants were determined using the overall grand means of importance and performance scores. Accordingly, the vertical axis was divided at an importance threshold of 0.05, while the horizontal axis was divided at a performance threshold of 3.40. These grand means served as reference points for classifying the criteria into the four IPA quadrants.

Findings on the quality of biodegradable packaging in the food industry were derived by identifying quality criteria and assessing their importance and

performance. To address RQ1, we identified 19 criteria and grouped them into four dimensions. For RQ2, we calculated the importance of each criterion individually and then used the IPA method to distinguish criteria based on these two factors. As previously noted, because packaging quality is a multidimensional concept, evaluating it solely from the perspectives of environmental compatibility and sustainability requirements is insufficient. Consequently, in addition to the fundamental capabilities of preserving food quality and safety, logistical and economic requirements, as well as customer and market expectations, must be met alongside environmental considerations.

Table 5. Importance weights, performance scores, and IPA quadrant classification of biodegradable packaging quality criteria.

Main dimensions	Criterions	Importance	Performance	Quadrant
Functional and technical	PT1- Packaging mechanical stability	0.0325	3.20	**3**
	PT2- Product shelf-life preservation	0.0509	2.95	**1**
	PT3- Resistance to environmental penetration	0.0439	4.10	**4**
	PT4- Food safety assurance	0.0867	4.15	**2**
Environmental	E1- Packaging biodegradability	0.0914	3.25	**1**
	E2- Packaging material recyclability	0.1026	3.35	**2**
	E3- Reduction of life -cycle environmental impacts	0.1365	3.40	**2**
	E4- Energy efficiency in packaging production	0.0584	3.10	**1**
Economic and logistic	EC1- Economic efficiency of packaging production	0.0510	3.80	**2**
	EC2- Packaging logistics efficiency	0.0405	2.90	**3**
	EC3- Minimization of raw material waste	0.0352	2.65	**3**
	EC4- Reusability of packaging materials	0.0264	3.05	**3**
	EC5- Packaging space efficiency	0.0229	3.30	**3**
Market and customer oriented	M1- Packaging visual quality	0.0365	3.40	**4**
	M2- Printability and brand identity capability	0.0265	3.10	**3**
	M3- Consumer acceptance and trust	0.0652	3.60	**2**
	M4- Customer environmental satisfaction	0.0409	3.35	**3**
	M5- Packaging user-friendliness	0.0309	3.50	**4**
	M6- Product information transparency	0.0210	3.25	**3**

As shown in **Figure 4**, the criteria of "packaging biodegradability," "product shelf-life preservation," and "energy efficiency in packaging production" fall within the first quadrant of the matrix; due to their high importance yet current performance levels, they are high-priority targets for improvement. Packaging biodegradability has a relatively high importance weight of 0.0914; the biodegradability of packaging highlights the significance of environmental compatibility in the evaluation of biodegradable food packaging. However, a performance score of 3.25 indicates that existing solutions only partially meet the expectations associated with this attribute. Therefore, although biodegradability is considered a defining characteristic in packaging, findings indicate a misalignment between current performance and this requirement. Consequently, there is a gap between environmental goals and the extent to which these goals are practically achieved. Similarly, energy efficiency in packaging production, with a weight of 0.0584 and a performance score of 3.10, indicates that environmental performance is influenced not only by factors related to the product's end-of-life

stage but also by aspects concerning the manufacturing process and energy requirements. Furthermore, production using alternative biodegradable materials does not conflict with the protective requirements for food products. These findings align with previous studies that have emphasized barrier properties, mechanical characteristics, thermal stability, and environmental impacts as fundamental components in packaging design (Khalid et al., 2024; Panou & Karabagias, 2023). A notable finding concerns product shelf-life preservation, which, with a relatively low importance weight of 0.0509 and a ranking of ninth out of 19 criteria, falls into the first quadrant of the IPA matrix due to its relatively low performance score of 2.95. This indicates that the importance ranking of a criterion does not necessarily align with the priority for its improvement. Although several other criteria were rated as more important by experts, the poor performance regarding shelf-life preservation highlights an urgent need for managerial attention to this specific attribute of biodegradable packaging. This feature plays a critical role in the food industry; if the packaging fails to deliver this capability effectively, it can accelerate product spoilage and increase food waste, ultimately undermining the environmental benefits of using biodegradable materials. Therefore, to improve biodegradable packaging, a balance must be struck between functional requirements and environmental considerations to ensure food quality and safety throughout storage and distribution. The results suggest that focusing solely on the development of biodegradable materials is insufficient; such development must be accompanied by the fulfillment of functional, protective, and energy-efficiency requirements within the production process. This integrated approach ensures that food preservation and the overall performance of the packaging are not sacrificed for the sake of environmental objectives.

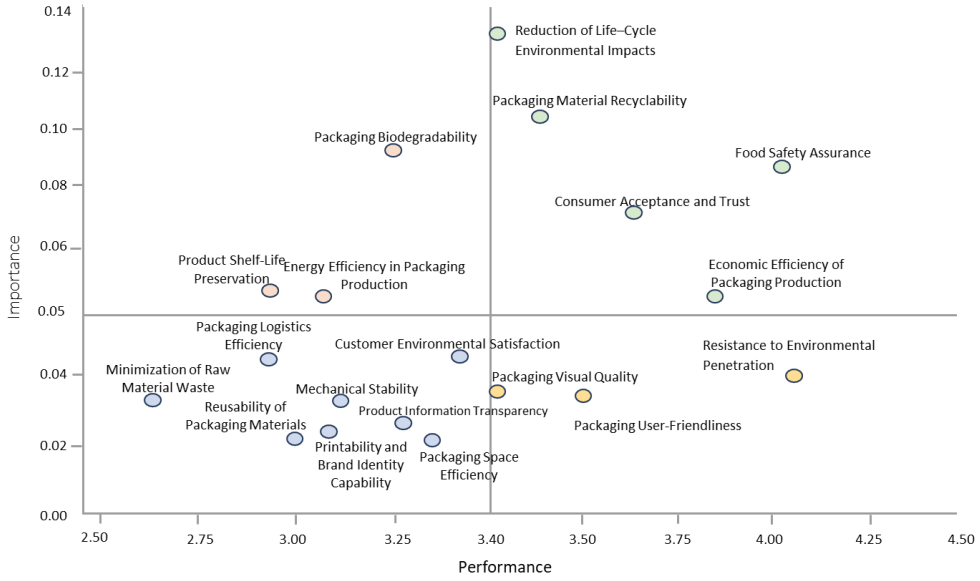

Figure 4. Importance–performance analysis matrix of biodegradable packaging quality criteria Note: The threshold values for the vertical axis (importance = 0.05) and the horizontal axis (performance = 3.40) were determined based on the overall mean scores.

The criteria reduction of life cycle environmental impacts, packaging materials recyclability, food safety assurance, consumer acceptance and trust, and economic efficiency in packaging production fall into the second quadrant of the IPA matrix, characterized by high importance and relatively favorable performance. These criteria represent the current strengths of biodegradable packaging, which should be maintained through continuous monitoring and improvement. Among all 19 criteria, reduction of life cycle environmental impacts holds the highest importance weight (0.1365),

underscoring the pivotal role of overall environmental performance in the assessment of biodegradable packaging. Although its performance score is 3.40, exceeding the overall average, further improvement is still required to meet environmental objectives. These results indicate that the assessment of environmental performance is as significant as the material's inherent biodegradability. Consequently, material composition, production processes, and end-of-life management conditions all influence the overall environmental sustainability of packaging solutions (Espinoza-Orias & Lundquist, 2025; Yilmaz et al., 2024). Therefore, the high importance assigned to this criterion suggests that the environmental benefits of biodegradable packaging should not be judged solely based on the biodegradable materials from which they are composed; rather, they must be evaluated from a life-cycle perspective. The next criterion in this quadrant is food safety assurance, which carries an importance weight of 0.0867 and a performance score of 4.15. Unlike the reduction of environmental impacts, which still requires improvement, this criterion has achieved a relatively high level of performance. This finding aligns with previous studies, which have argued that environmental improvements in food packaging must not compromise food safety, product integrity, or protective functionality (Khalid et al., 2024; Panou & Karabagias, 2023). From a practical standpoint, these results underscore the necessity of maintaining the protective properties of biodegradable packaging when developing and adopting environmentally preferable materials. Similarly, the positioning of the packaging material recyclability criterion highlights end-of-life considerations that extend beyond mere biodegradation, emphasizing the need to account for the potential recovery and management of packaging materials. Furthermore, the economic efficiency of packaging production and consumer acceptance and trust indicate that the successful adoption of biodegradable packaging depends not only on its environmental and technical performance but also on production feasibility and market acceptance. Accordingly, complementary factors, such as the economic viability of production and consumer trust, must be considered to achieve broader adoption of sustainable packaging solutions. Previous studies have emphasized that vague or insufficient sustainability claims can increase consumer skepticism and undermine trust (Dörnyei et al., 2023; Vaikma et al., 2025). Therefore, maintaining the strengths identified in this quadrant requires an integrated approach that preserves food safety, enhances life-cycle environmental performance, supports economic feasibility, and fosters consumer trust through credible sustainability communication.

The remaining criteria packaging logistics efficiency, customer environmental satisfaction, minimization of raw material waste, packaging mechanical stability, reusability of packaging materials, printability and brand identity capability, product information transparency, and packaging space efficiency fall into the third quadrant of the IPA matrix, characterized by relatively low importance and low performance. Although these criteria represent a lower immediate priority for improvement compared to those in the first quadrant, this does not imply that they should be ignored. Notably, the criterion minimization of raw material waste received the lowest performance score (2.65) among all identified criteria; this indicates an operational weakness, despite its relatively low importance weight, that warrants attention. This finding is critical, as the reduction of material waste, logistics efficiency, and the optimization of packaging space can significantly influence resource utilization and supply chain operations (Cozzolino & De Giovanni, 2023; Yilmaz et al., 2024). Therefore, their relatively low priority within the IPA matrix does not signify a lack of operational significance; rather, it should be interpreted within the context of resource allocation. Furthermore, the relatively low importance assigned to packaging mechanical stability does not negate its functional significance. This is particularly relevant when considering specific product characteristics and distribution conditions (Panou & Karabagias, 2023). Similarly, the placement of customer environmental satisfaction and product information transparency in this quadrant, while consumer acceptance and trust fall into the second quadrant, indicates that various aspects of packaging quality, from the consumer's perspective, are not perceived in the same way by experts. This distinction highlights the necessity of differentiating between

overall consumer acceptance and satisfaction with environmental attributes or access to transparent product information. Previous studies have emphasized that consumer expectations and communication practices regarding sustainability can influence individual perceptions of more eco-friendly packaging (Dörnyei et al., 2023; Vaikma et al., 2025). Recent empirical studies have further demonstrated that packaging material, color, and aesthetic design can shape consumers' perceptions of food products and influence their willingness to consume and purchase intentions (Berthold et al., 2024; Hu et al., 2025). Similarly, resistance to environmental factors and external damage contributes to the protective functionality of packaging under different handling, storage, and distribution conditions (Cheng et al., 2024b; Panou & Karabagias, 2023). Consequently, resource allocation decisions must consider both the relative priorities identified by the IPA and the minimum technical, safety, and regulatory requirements applicable to food packaging.

Table 6. Criterion rankings under different weight perturbation scenarios.

Code	Baseline rank	+10%	+20%	+30%	+40%	+50%	-10%	-20%	-30%	-40%	-50%
PT1	14	13	12	10	9	9	15	17	18	19	19
PT2	8	7	6	5	5	5	8	10	12	15	17
PT3	9	9	7	7	6	5	11	13	15	17	18
PT4	4	3	2	2	2	2	4	4	5	6	9
E1	3	3	2	2	2	1	4	4	5	6	8
E2	2	2	2	2	1	1	2	4	4	5	6
E3	1	1	1	1	1	1	1	1	2	4	4
E4	6	6	5	5	5	4	6	8	10	13	15
EC1	7	7	6	5	5	5	8	10	12	15	17
EC2	11	9	9	7	7	6	12	14	15	17	19
EC3	13	12	10	9	9	7	14	15	17	18	19
EC4	17	16	15	14	12	12	17	18	19	19	19
EC5	18	18	16	16	15	14	19	19	19	19	19
M1	12	12	10	9	7	7	13	15	17	18	19
M2	16	16	15	14	12	12	17	18	19	19	19
M3	5	5	5	5	4	3	5	6	8	11	13
M4	10	9	9	7	7	6	11	13	15	17	19
M5	15	14	12	12	10	9	15	17	18	19	19
M6	19	18	18	16	16	15	19	19	19	19	19

Ultimately, the results underscore the need to address functional, technical, environmental, economic, logistical, and market and customer-oriented dimensions simultaneously to improve the quality of biodegradable packaging in the food industry. This study contributes further innovation to the field by having experts identify and weigh the criteria, as well as evaluate their relative importance alongside actual performance. The findings distinguish between criteria requiring immediate improvement, those where performance must be maintained, and those with lower relative priorities. This approach offers a systematic basis for prioritizing corrective actions and making targeted investments to develop biodegradable packaging. Consequently, improvement and decision-making strategies should not focus solely on criteria weights or performance metrics; rather, they must simultaneously consider the importance of each criterion, its performance status, and the technical and safety requirements of food packaging.

Finally, a one-at-a-time sensitivity analysis was employed to evaluate the stability of the criterion rankings. Accordingly, the weight of each criterion was independently adjusted by increasing or decreasing it by 10% to 50% ,while the weights of the other criteria remained constant. Based on these adjusted weights, the criteria were re-ranked from 1 to 19, representing the order from highest to lowest priority. The results indicate that altering the weight of an individual criterion can shift its ranking, with the extent of the shift corresponding to the magnitude of the weight change. The resulting changes in rankings are presented in **Table 6**. These findings demonstrate the sensitivity of the criteria's relative priorities to weight fluctuations; consequently, the sensitivity analysis results serve as a valuable supplement to the initial rankings derived from the BWM method.

Overall, this study contributes to the field of biodegradable food packaging by providing an integrated assessment of quality criteria utilizing a combination of BWM and IPA. First, by identifying 19 key criteria influencing the quality of biodegradable packaging, categorized into four primary dimensions, this study addresses the multidimensional nature of the quality concept. This highlights the broad scope of packaging quality, which encompasses safety requirements, production and logistical efficiency, and consumer considerations. Second, by calculating the importance of these criteria using the BWM weighting technique and evaluating their performance, an IPA matrix was developed to prioritize areas for improvement. This distinction is analytically significant, as it indicates the level of urgency for addressing specific criteria. For instance, based on the IPA matrix and expert input, criteria such as E3, E2, PT4, M3, and EC1 are identified as strengths of the packaging system, requiring measures to maintain their current status. Conversely, criteria such as E1, PT2, and E4, while deemed highly important, do not currently demonstrate satisfactory performance, necessitating targeted interventions to improve them. Accordingly, the findings of this study, based on the hybrid BWM-IPA approach, are significant from both theoretical and managerial perspectives. Furthermore, the sensitivity analysis conducted at the end of the study, designed to examine how changes in criterion weights affect the ranking, complements the evaluation process. Overall, these findings can pave the way for further assessments regarding the criteria that influence the quality of biodegradable packaging.

In addition to theoretical implications, this study offers practical implications for key supply chain stakeholders ,ranging from raw material suppliers to end consumers. By leveraging these findings and actionable recommendations, stakeholders at the upstream end of the chain can create added value for consumers, who represent the final link in the supply chain. Based on the criteria introduced in this study, some of the actionable recommendations for supply chain participants are as follows:

Raw material suppliers, as the initial actors in the supply chain for the production of biodegradable packaging, are advised to compile a comprehensive set of reliable technical data covering composition, material properties, processing conditions, and environmental documentation ,and supply raw materials in accordance with these specifications. These materials are then delivered to biodegradable packaging manufacturers, who are tasked with designing and fabricating the packaging while prioritizing technical performance, shelf-life preservation, safety, and energy efficiency during the production process. The resulting packaging is subsequently supplied to food producers, as well as transport, warehousing, and distribution firms. It is recommended that, prior to full-scale production, these stakeholders evaluate prototype packaging within a smaller, targeted pilot setting. This evaluation should be based on the key requirements identified in this research, prioritized via an IPA matrix, and involve rigorous testing. Such testing should encompass mechanical properties (e.g., tensile strength and elongation at break), barrier properties (e.g., water vapor transmission rate [WVTR] and oxygen transmission rate [OTR]), and biodegradation assessments to verify suitability for industrial composting or soil degradation, alongside other relevant industry-standard tests. Furthermore, it is recommended that safety assessments regarding contact with food, as well as the determination of shelf life throughout the product's lifecycle, be conducted in a manner appropriate to the specific product and the type of packaging material. From

the range of prototypes developed, the packaging that best satisfies safety requirements, physical durability, storage space optimization, and the high-priority criteria identified in the IPA matrix should be selected for mass production. This final selection can help ensure that the selected packaging addresses sustainability, functional and technical performance, economic viability, logistics, and market customer-oriented requirements. Subsequently, wholesalers and retailers distribute food products housed in biodegradable packaging. At this stage, stakeholders can gather data regarding the status of the products and their packaging, as well as market feedback. This can be achieved through mechanisms such as "Retail Data Sharing" (for exchanging information on sales, inventory, damages, and returns), "EDI and Supply Chain Information Systems" (for the structured exchange of operational and commercial data), and "semi-structured interviews" (to identify operational challenges and capture the qualitative experiences of stakeholders). This information can then be shared with upstream stakeholders to support continuous improvement of biodegradable packaging. Finally, it is recommended that consumer feedback collected from the end-users of the supply chain be shared with suppliers and manufacturers. This feedback, gathered via channels such as post-purchase surveys, online customer reviews (eWOM), and QR-code-based feedback systems, would indicate the extent to which the packaging meets consumer expectations based on market-driven and customer-oriented criteria. Throughout the supply chain, support entities and waste management organizations can assist manufacturers of eco-friendly packaging by developing infrastructure, providing technical guidance, issuing valid certifications, and, where feasible, offering tax exemptions. Furthermore, these entities can enhance consumer awareness regarding the management of biodegradable waste and promote the adoption of such packaging through environmental events and promotional campaigns.

Conclusion

This study aimed to identify, classify, and evaluate quality criteria for biodegradable packaging in the food industry. To achieve this objective, two research questions were formulated. A mixed-method approach was employed: a systematic SLR was used to identify the criteria, while the BWM and IPA were utilized to evaluate and prioritize them. Ultimately, 19 criteria influencing the quality of biodegradable packaging were classified into four dimensions: functional and technical, environmental, economic and logistical, and market and customer-oriented. The results indicate that, in addition to environmental compatibility and biodegradability, factors such as technical performance, food safety, consumer expectations, and sustainable development goals must be considered simultaneously to achieve high-quality biodegradable packaging. The IPA matrix reveals that the relative importance of a given criterion does not necessarily align with its current performance. Furthermore, a sensitivity analysis demonstrates that while the ranking of criteria shifts under different weighting scenarios, the magnitude of these changes varies across the individual criteria. From a theoretical perspective, this study employs a combined evaluation approach to provide a structured framework for prioritizing criteria, thereby contributing to the existing body of research on biodegradable food packaging. From a practical standpoint, the findings offer actionable guidance for packaging and food manufacturers, retailers, and policymakers aimed at enhancing the quality of biodegradable packaging. The results indicate that investment should focus primarily on improving packaging biodegradability, developing recyclable materials, reducing life-cycle environmental impact, and maintaining food safety. Furthermore, examining resource allocation and prioritizing key criteria can improve operational efficiency, reduce food waste, and strengthen companies' competitive advantage. The findings also underscore the importance of market and customer-oriented dimensions such as packaging design, sustainability labeling, and consumer awareness in supporting the successful adoption and commercialization of biodegradable packaging.

This study has certain limitation:

1. The scope was restricted to studies published within a specific timeframe and sourced from

selected scientific databases; consequently, some relevant studies may have been overlooked.

2. Another limitation of this study is the relatively small number of experts (n = 9) involved in evaluating the performance of the 19 biodegradable packaging quality criteria. Although this panel size was considered appropriate for the BWM-based assessment and expert judgment process, relying on a limited number of respondents to evaluate performance may restrict the statistical representativeness and generalizability of the findings. In particular, the performance scores reflect the assessments of selected experts rather than a comprehensive measurement of market-wide performance. Therefore, the results should be interpreted as expert-based evaluations of the current performance of biodegradable packaging. Future research could address this limitation by involving a larger and more diverse sample of quality managers, packaging technologists, and food manufacturers to obtain a broader assessment of performance across the food packaging industry.

3. This study focused on identifying and analyzing quality dimensions without examining the causal relationships between the criteria.

Accordingly, future research should prioritize and model the relationships between the quality dimensions of biodegradable packaging by employing methods such as DEMATEL, ISM, SEM, and fuzzy-based approaches. Furthermore, conducting empirical studies in other manufacturing industries, examining consumer behavior toward biodegradable packaging, and integrating LCA with multi-criteria decision-making models can advance knowledge.

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Conflicts of interest

The authors declare no conflicts of interest.

Disclaimer

No formal ethical approval was obtained for this study. Informed consent was obtained from all participants involved in the study before their participation. The authors used ChatGPT (OpenAI) to assist with language editing and improve the linguistic clarity of the manuscript. All AI-assisted content was reviewed and revised by the authors, who took full responsibility for the accuracy, originality, and integrity of the final manuscript.

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